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(12) **United States Patent**  
**Bonn**

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(54) **THERMALLY TUNED COAXIAL CABLE FOR MICROWAVE ANTENNAS**

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H01B 11/1804; H01B 11/1808; H01B  
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See application file for complete search history.

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This patent is subject to a terminal disclaimer.

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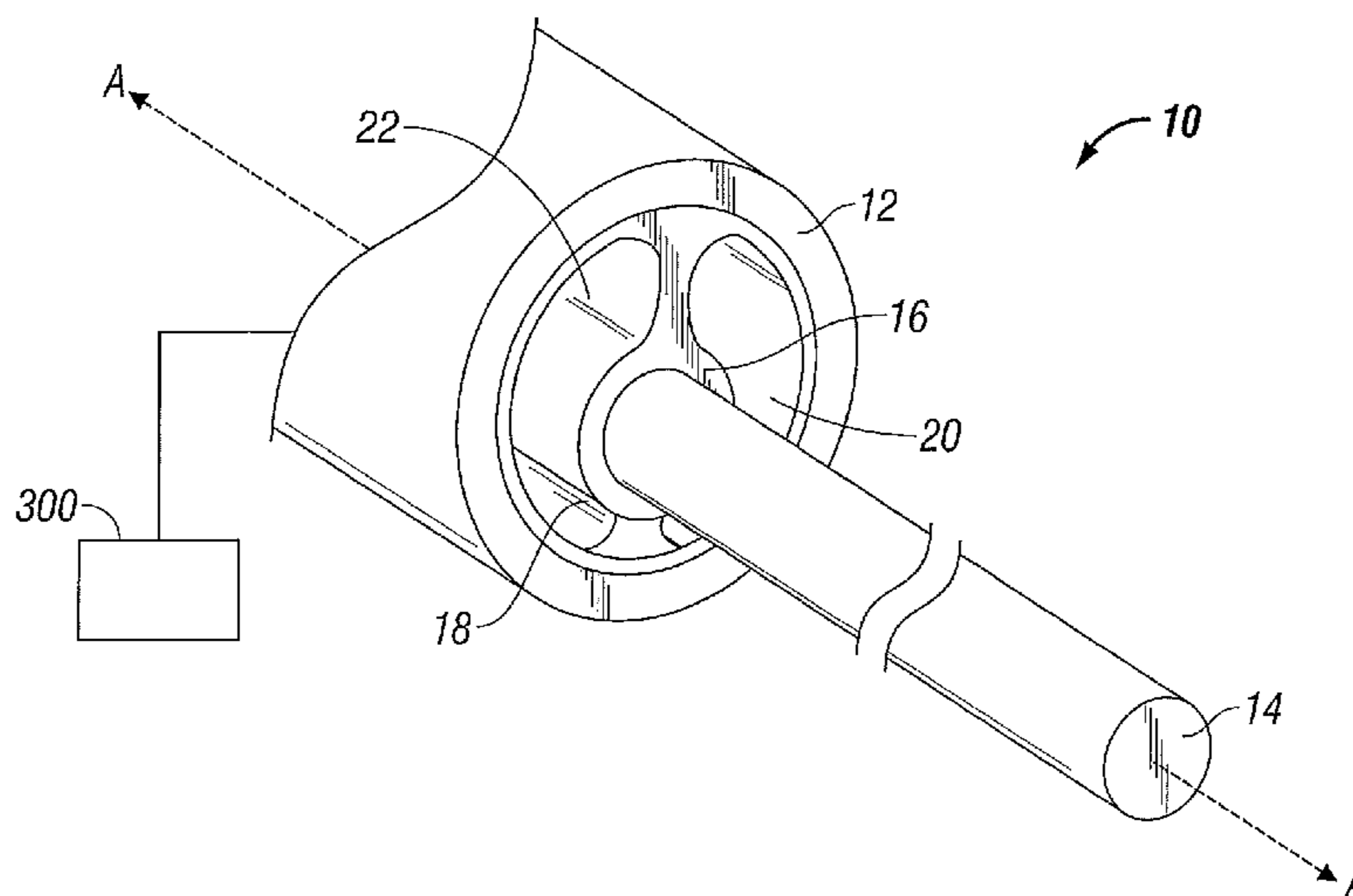
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(57) **ABSTRACT**

A coaxial cable, including an inner conductor and an outer conductor surrounding the inner conductor and a thermally responsive material positioned between the outer conductor and the inner conductor. The outer conductor is in a generally concentric relationship to the inner conductor and the inner and outer conductors are adapted to connect to an energy source. A thermal change in the thermally responsive material alters the generally concentric relationship between the outer conductor and the inner conductor.

**16 Claims, 8 Drawing Sheets**



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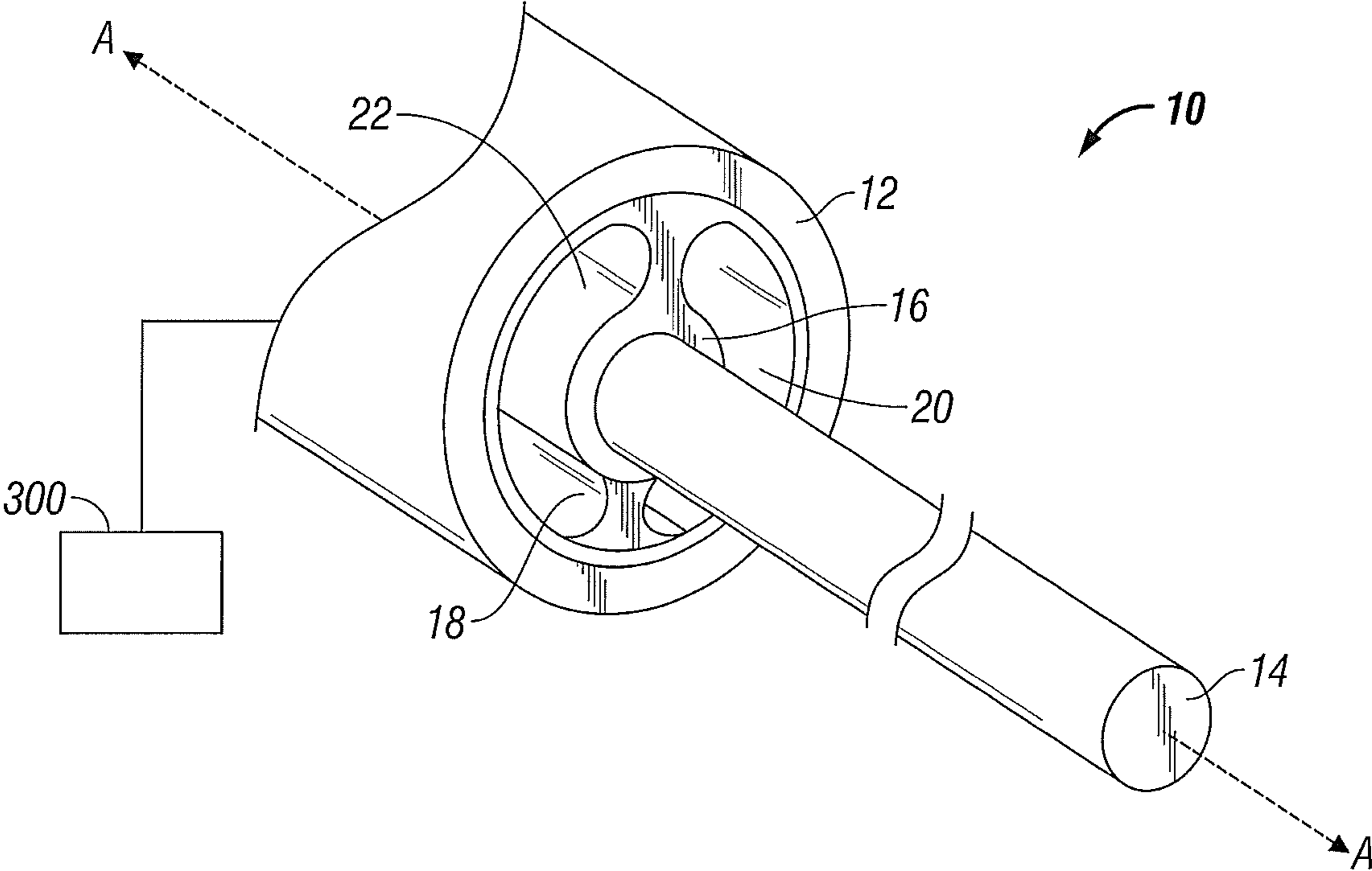


FIG. 1A

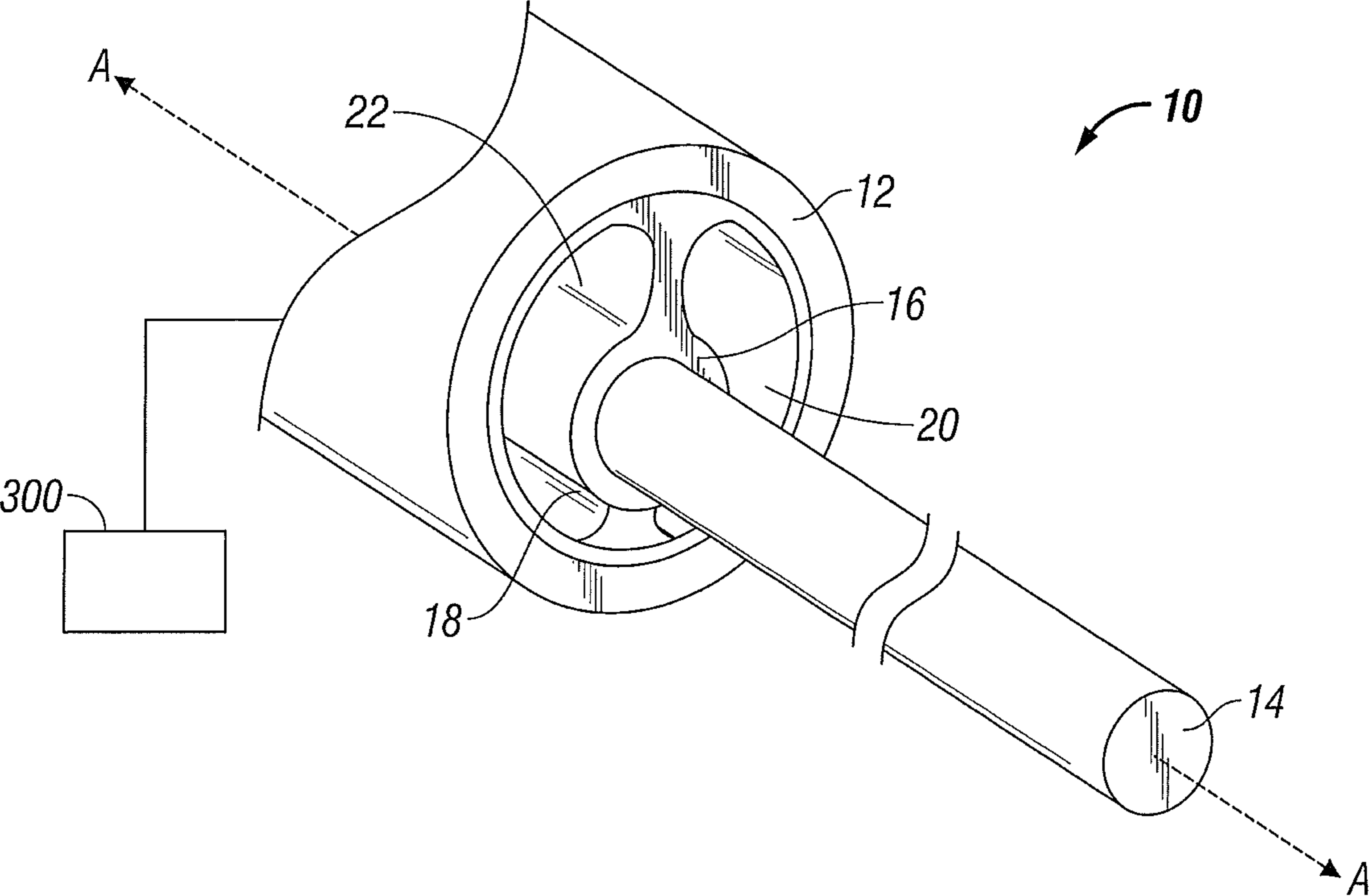


FIG. 1B

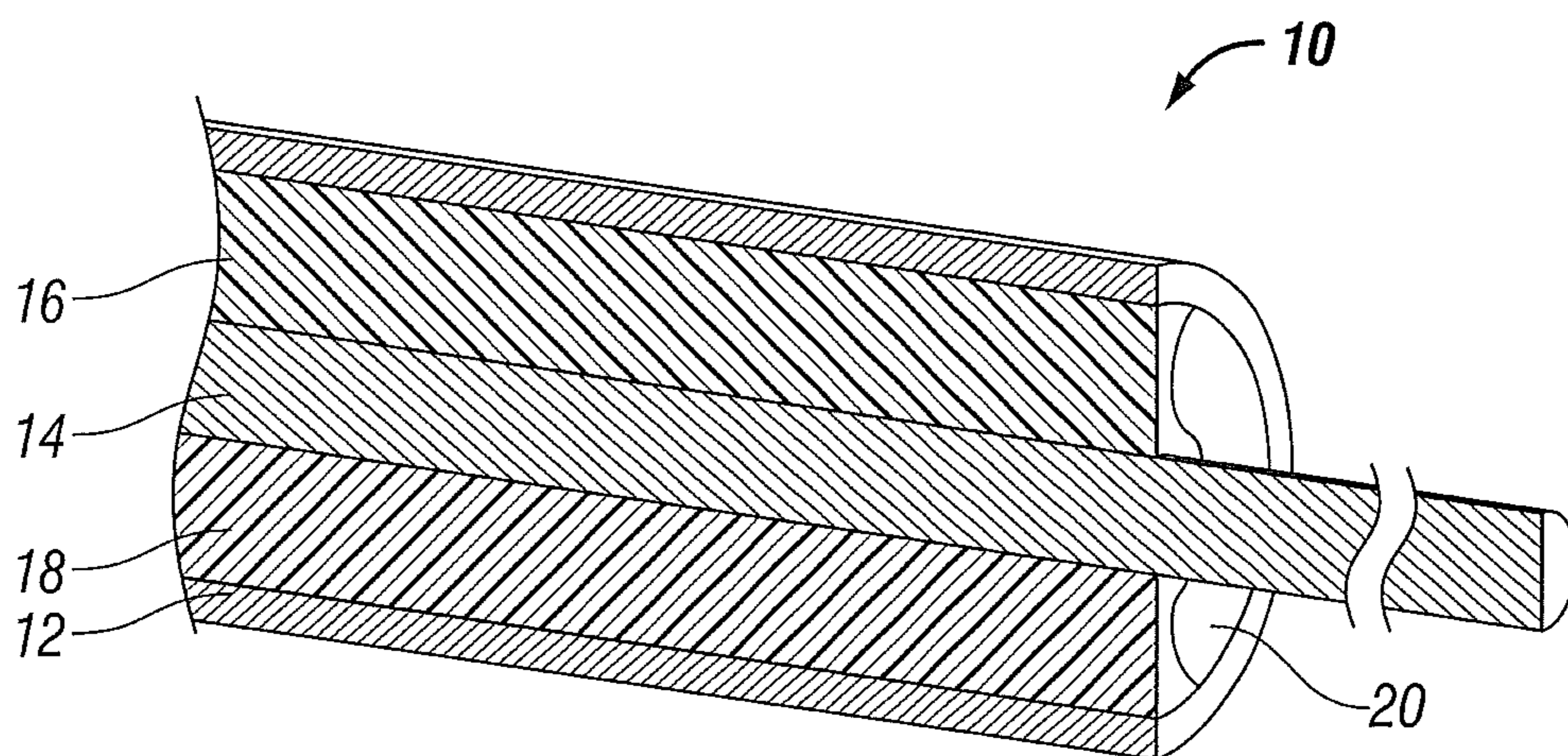


FIG. 1C

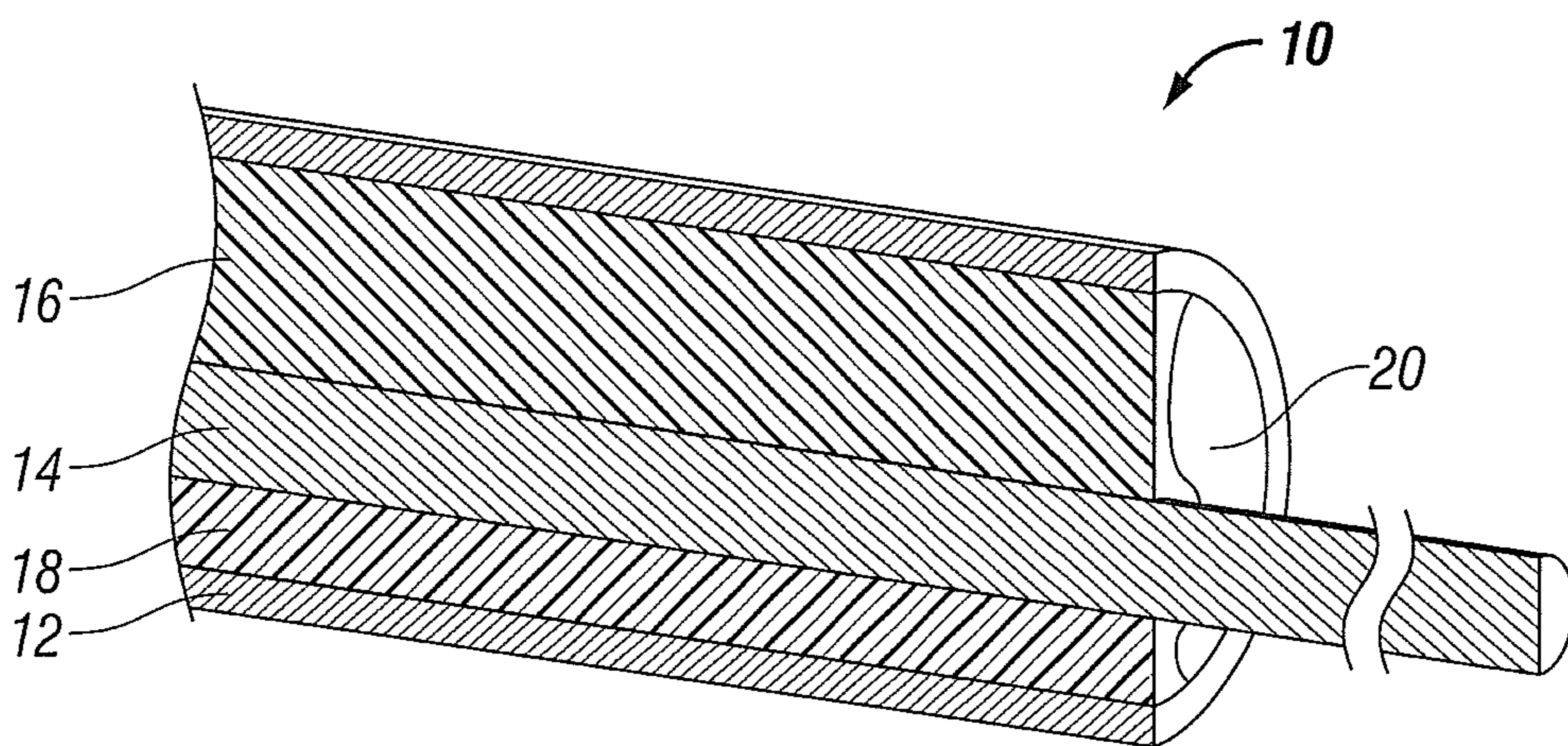


FIG. 1D



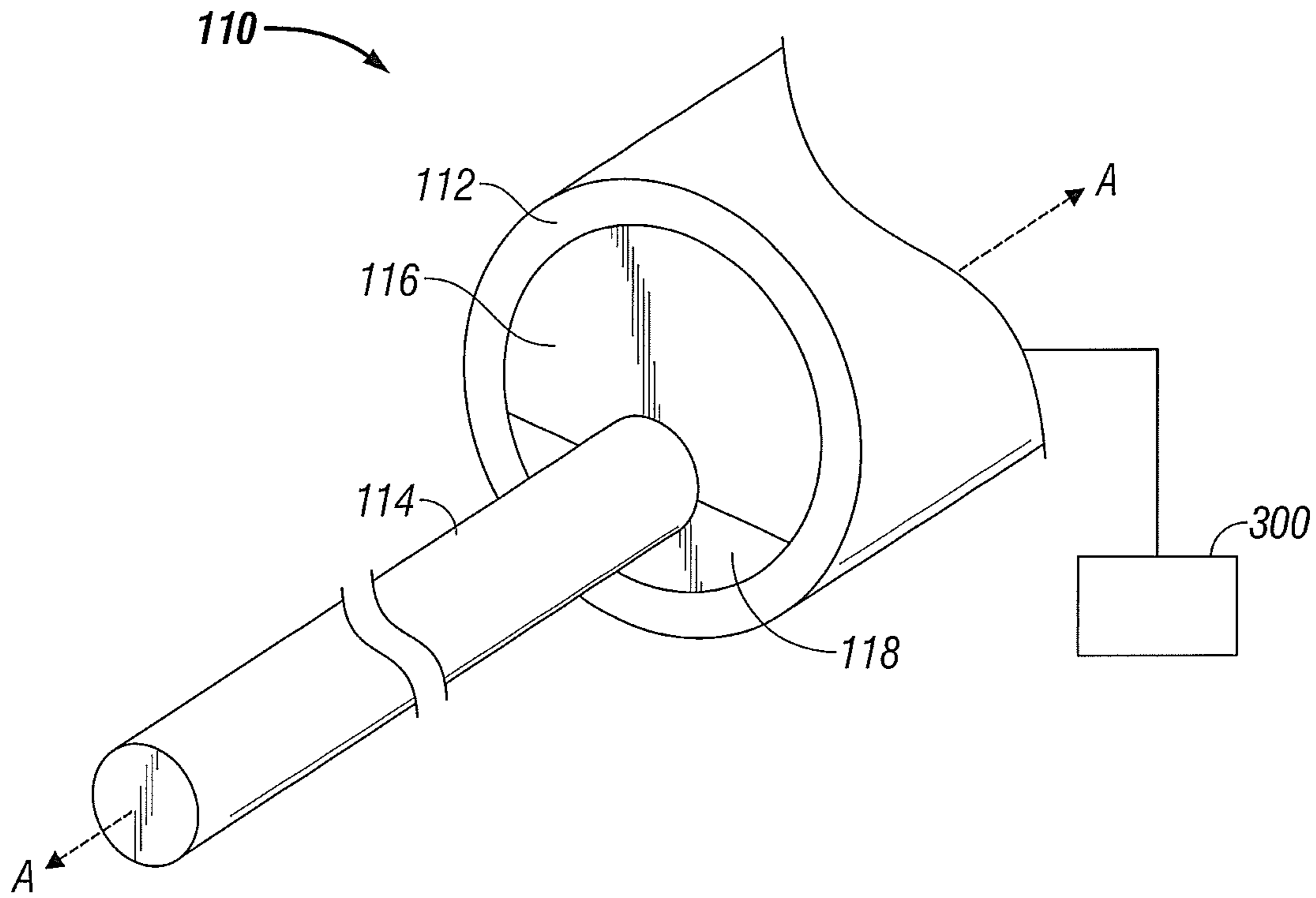


FIG. 2A

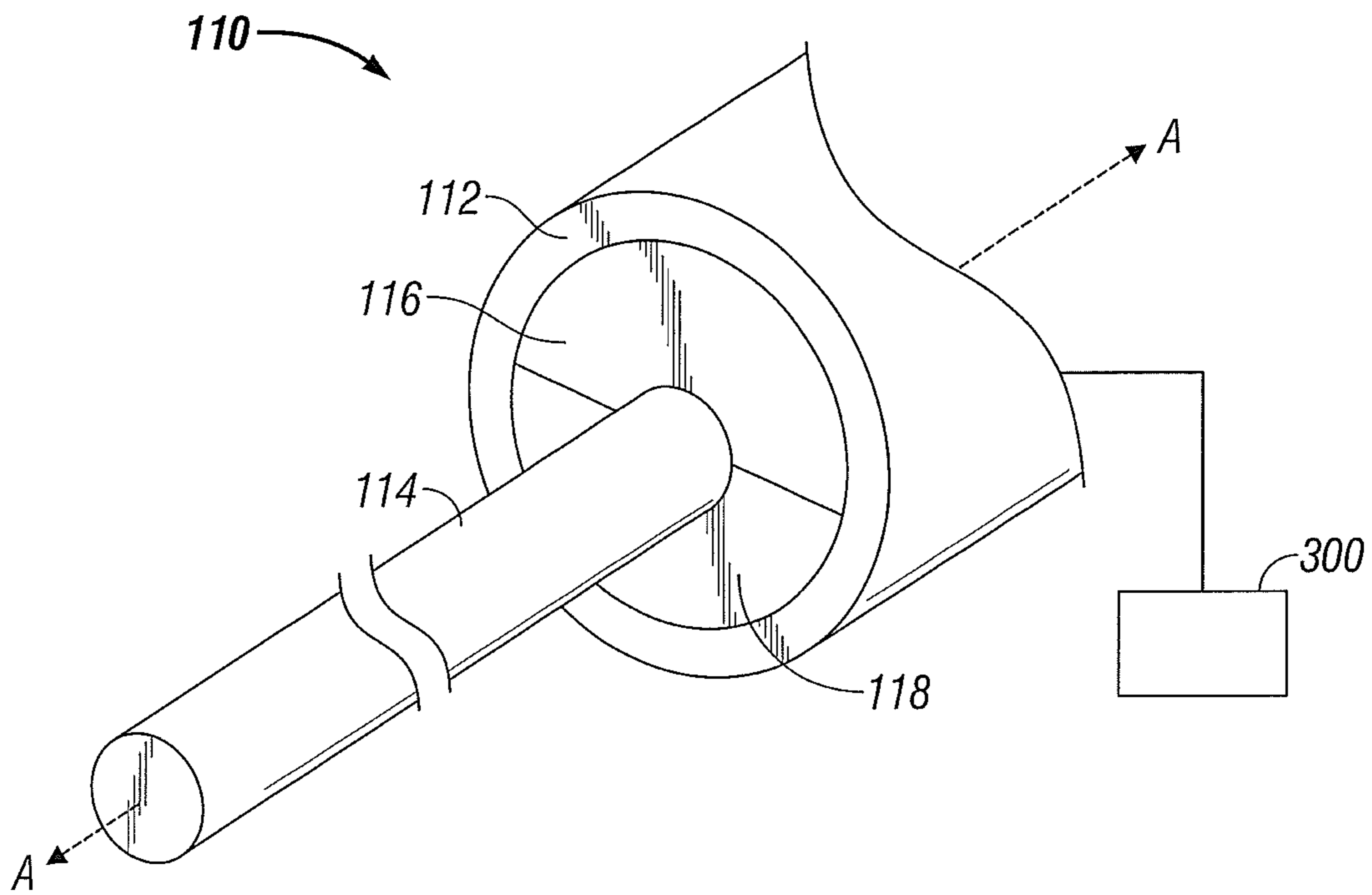


FIG. 2B

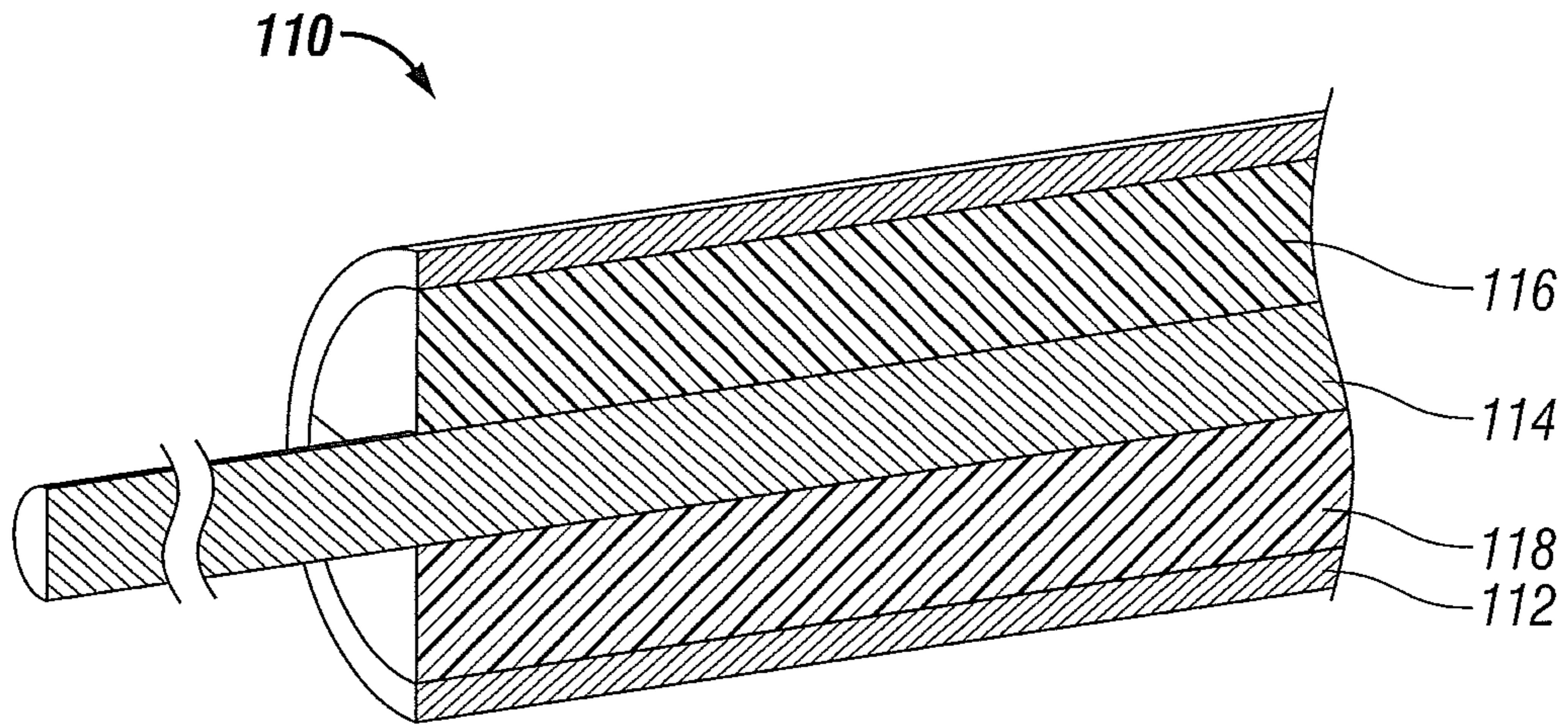


FIG. 2C

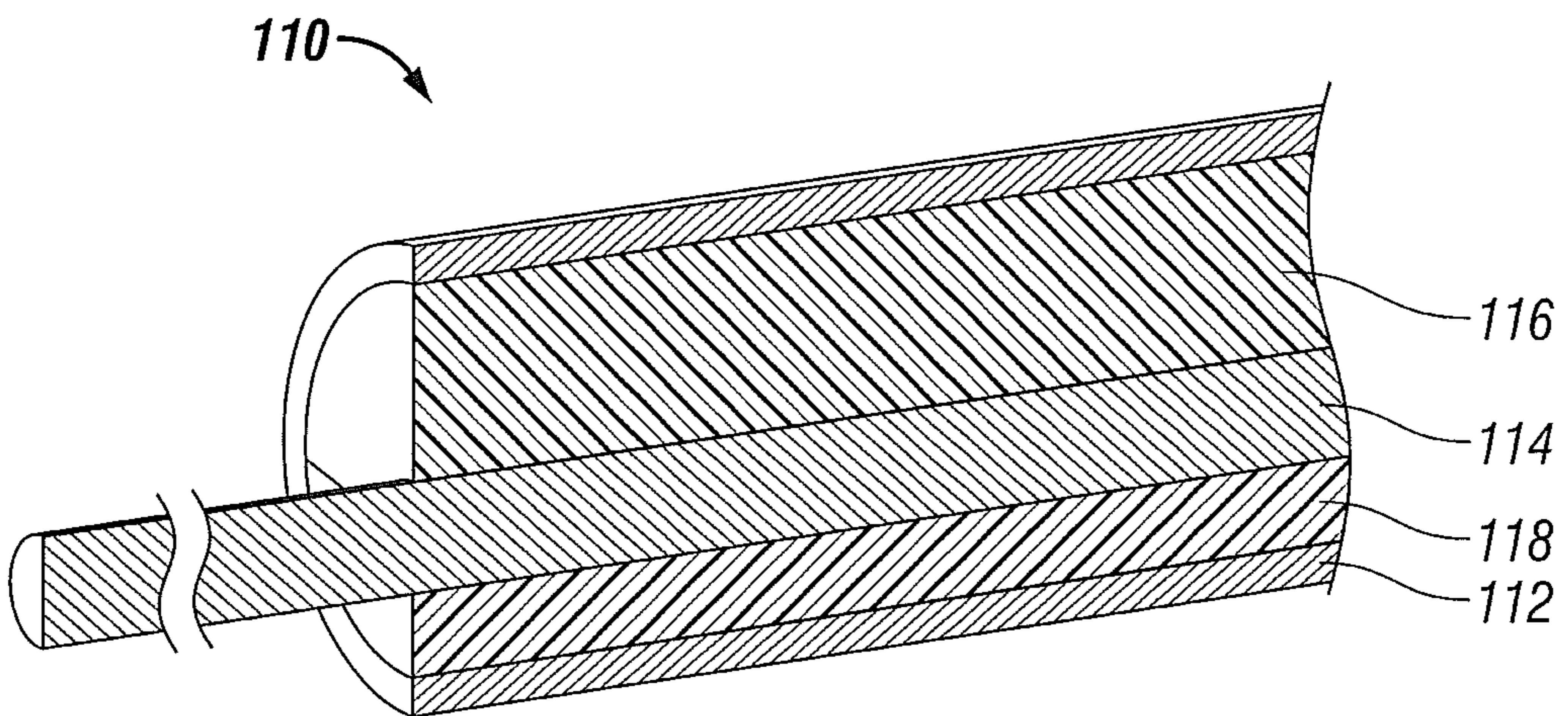


FIG. 2D

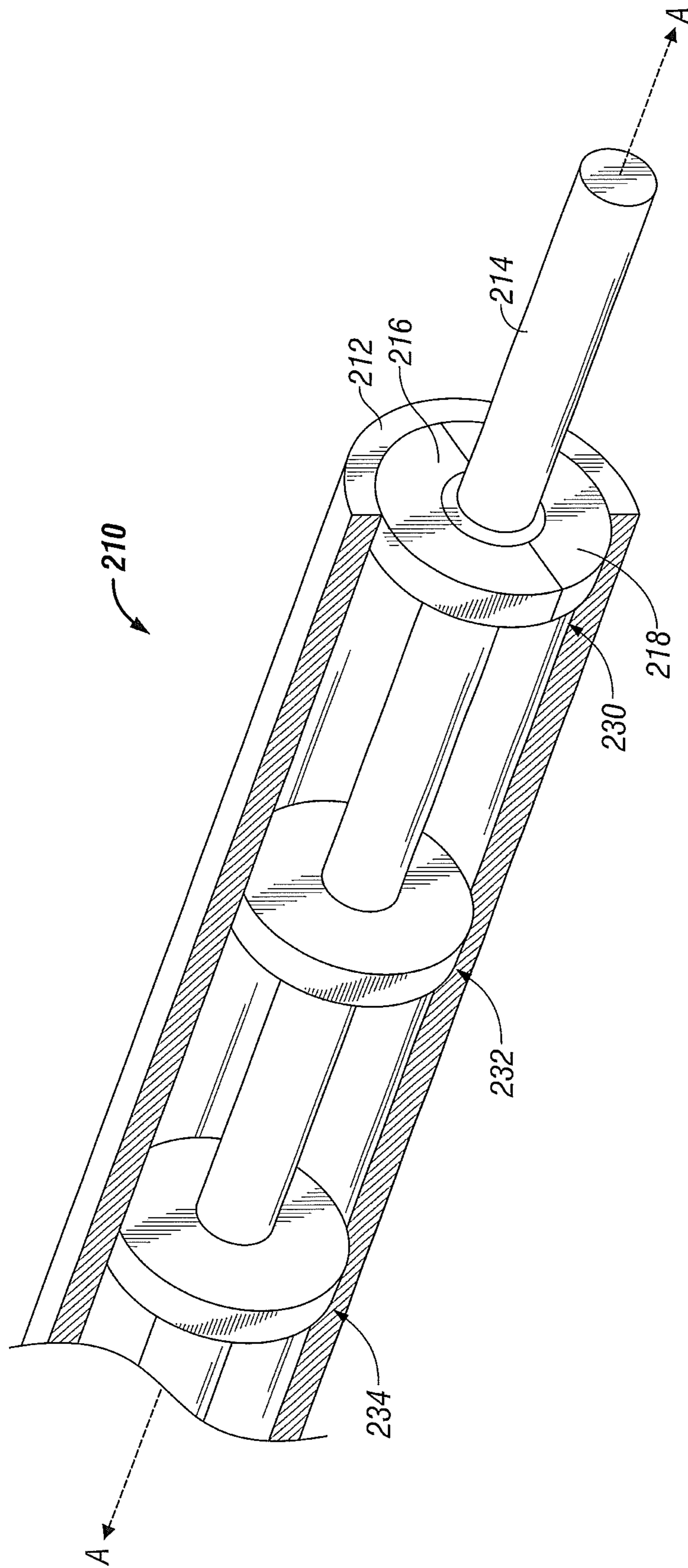


FIG. 3

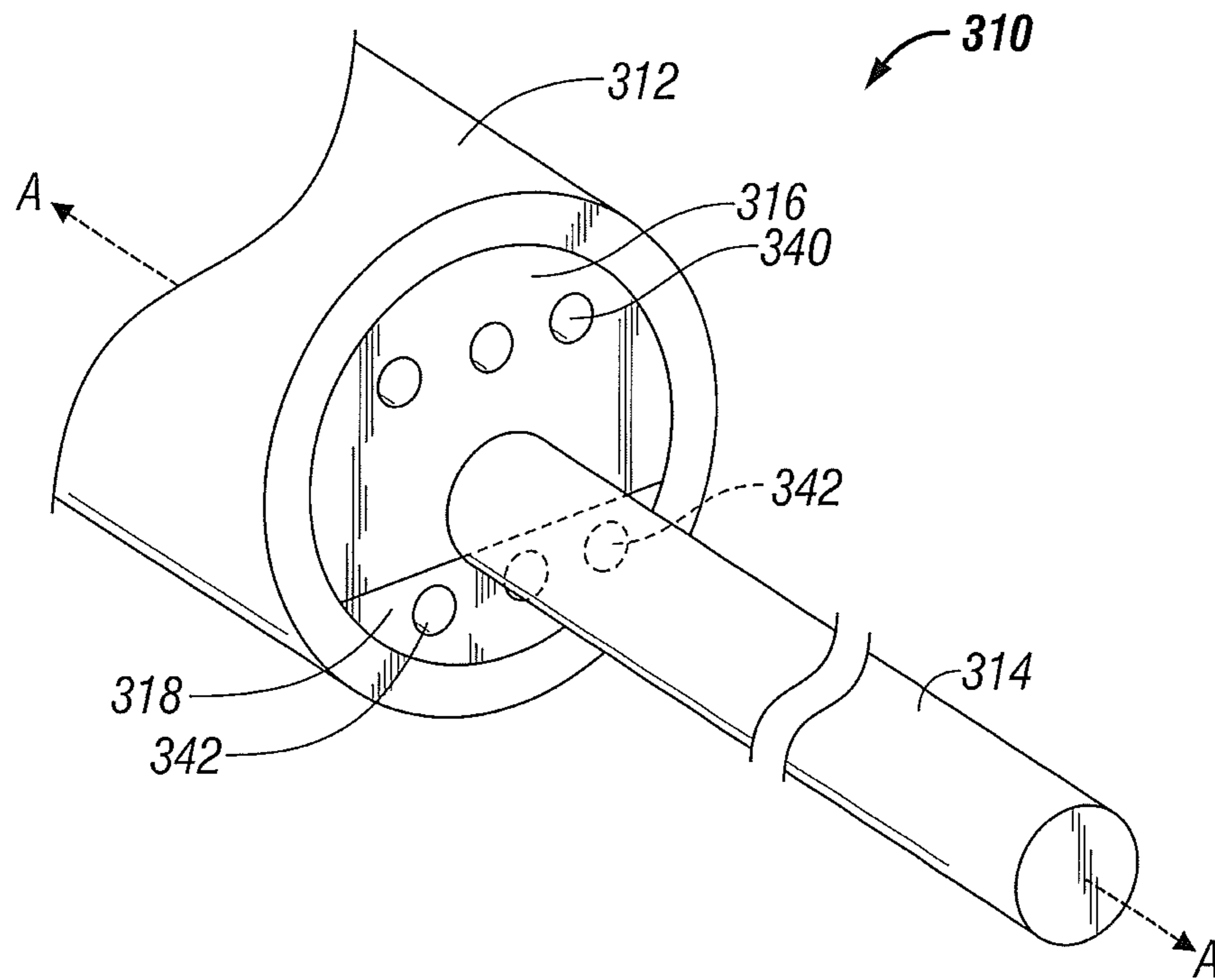


FIG. 4A

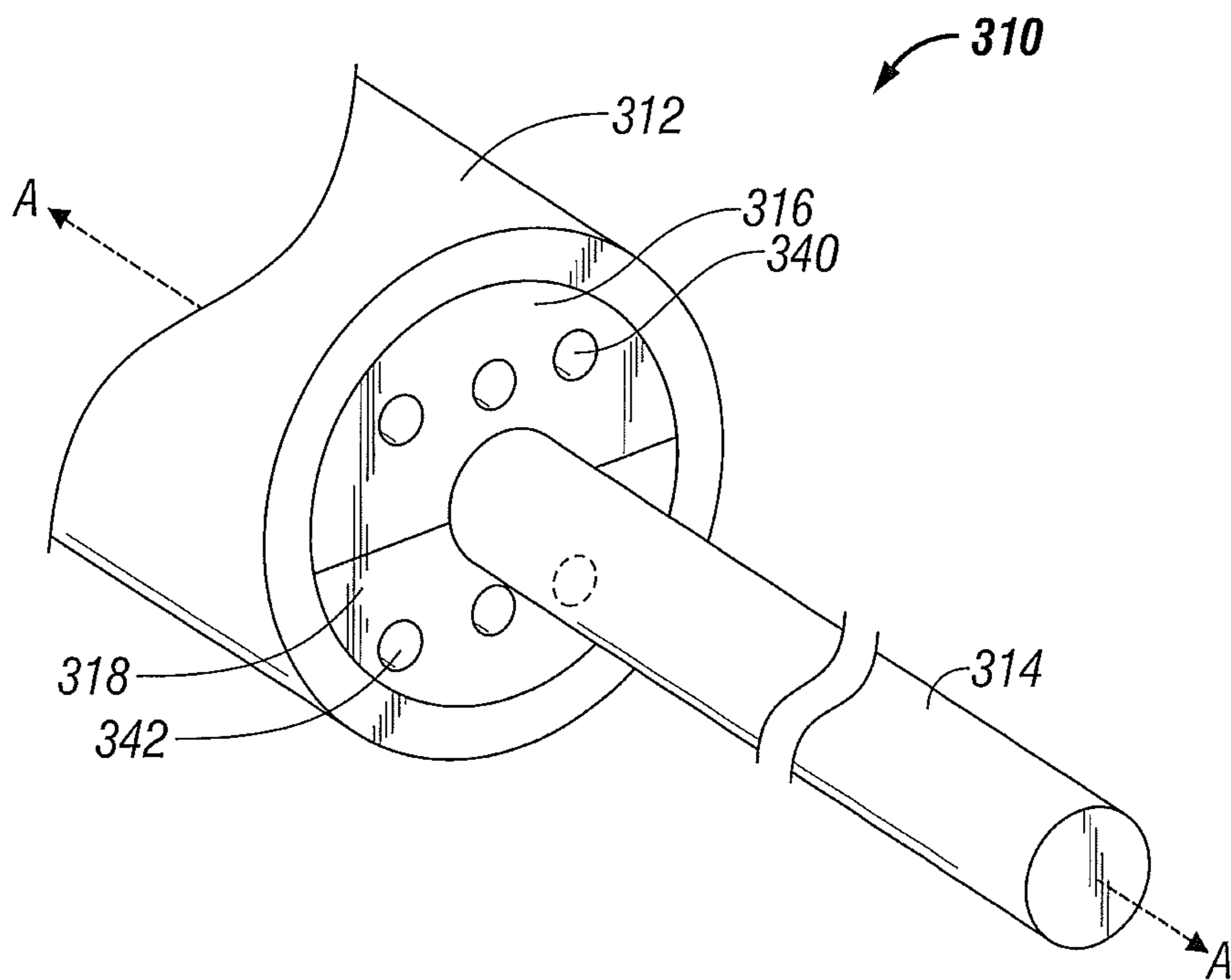


FIG. 4B

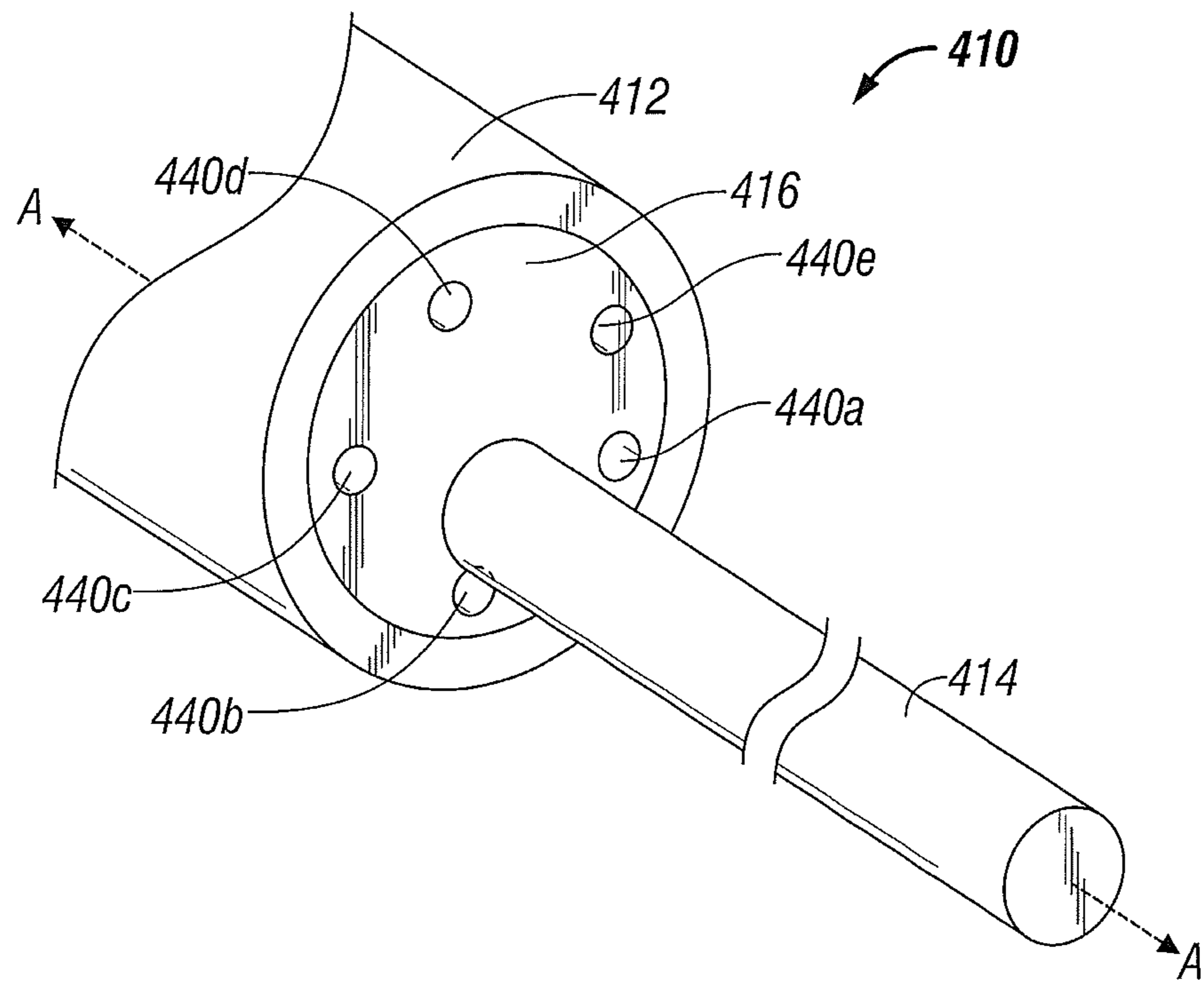


FIG. 5A

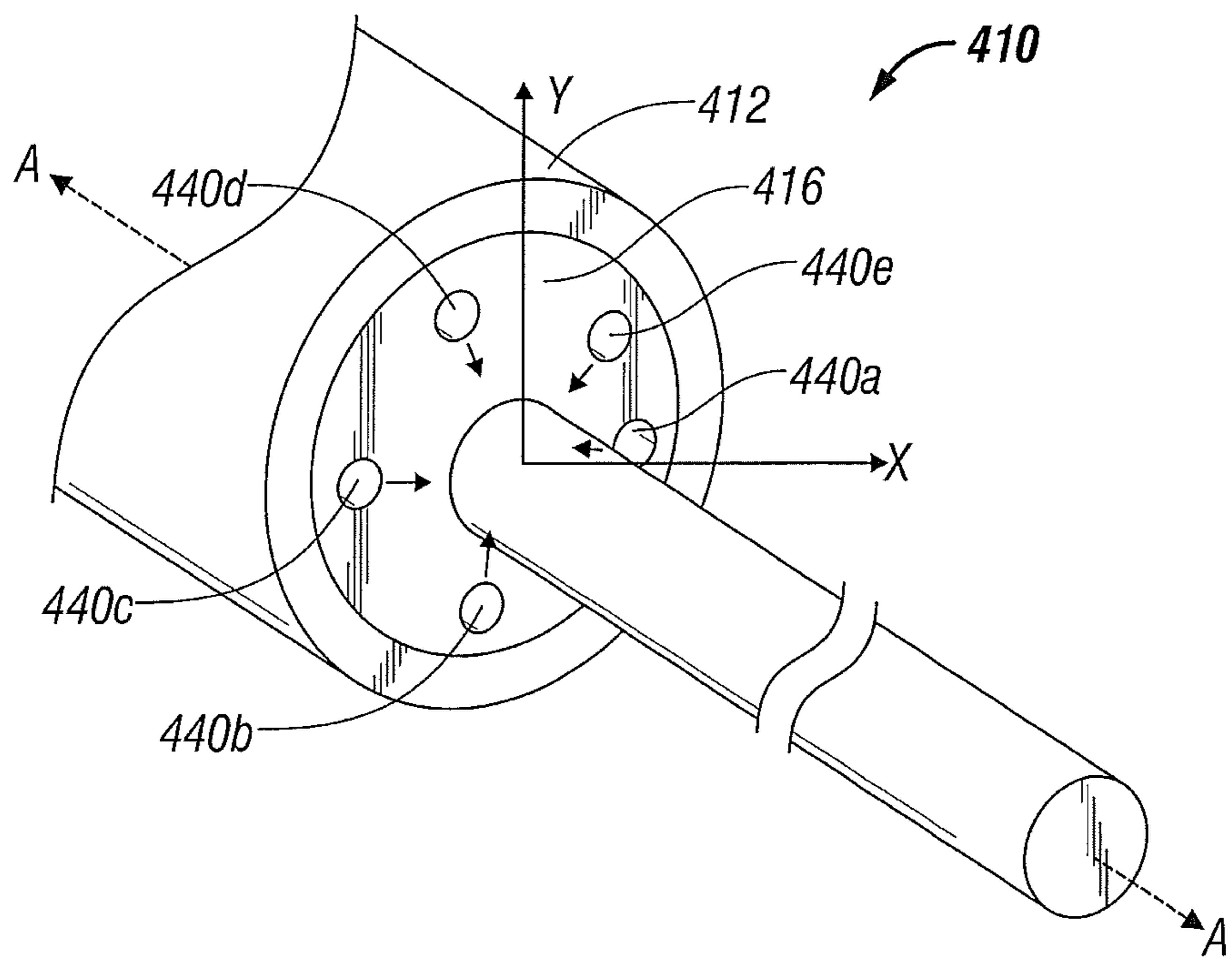


FIG. 5B

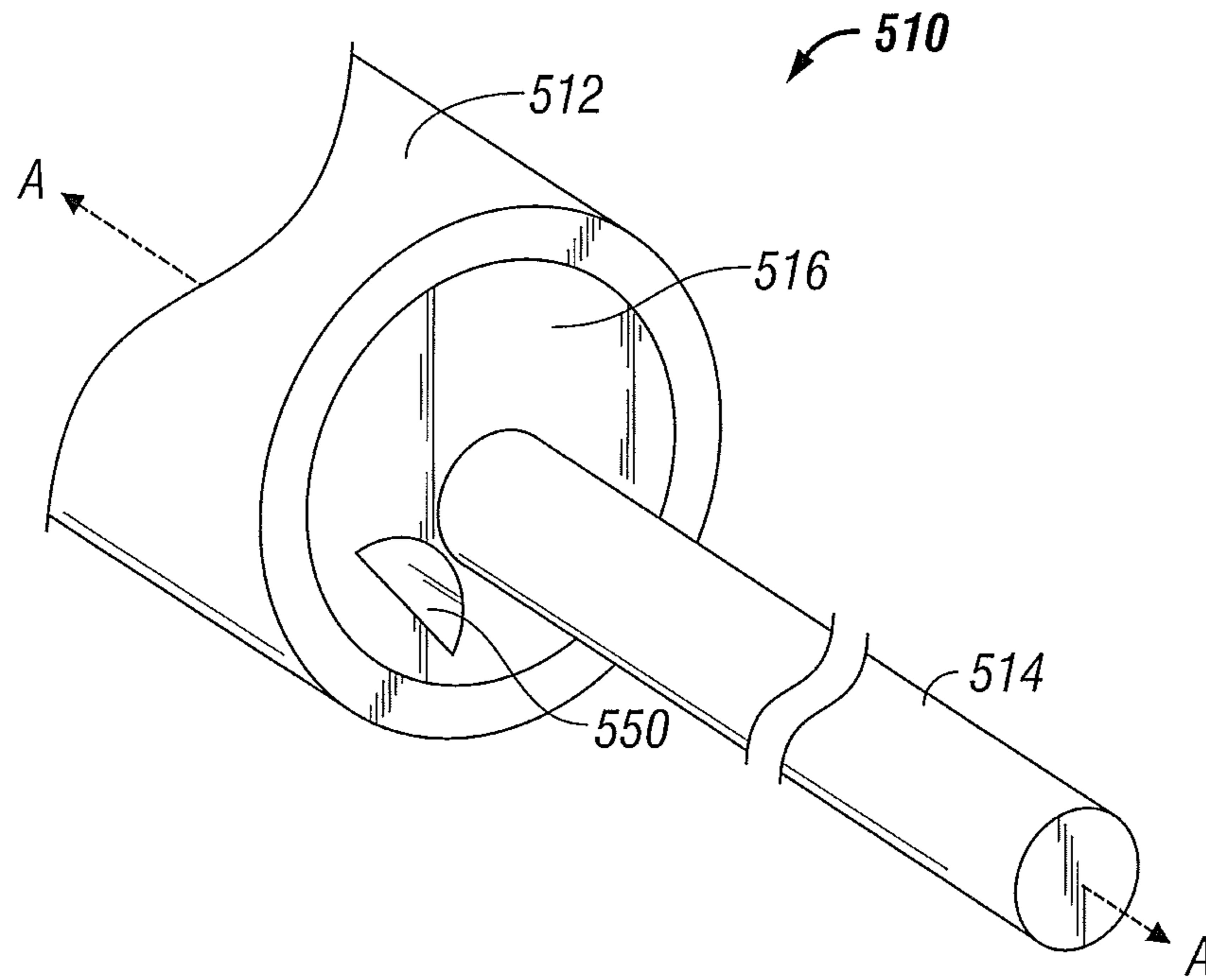


FIG. 6

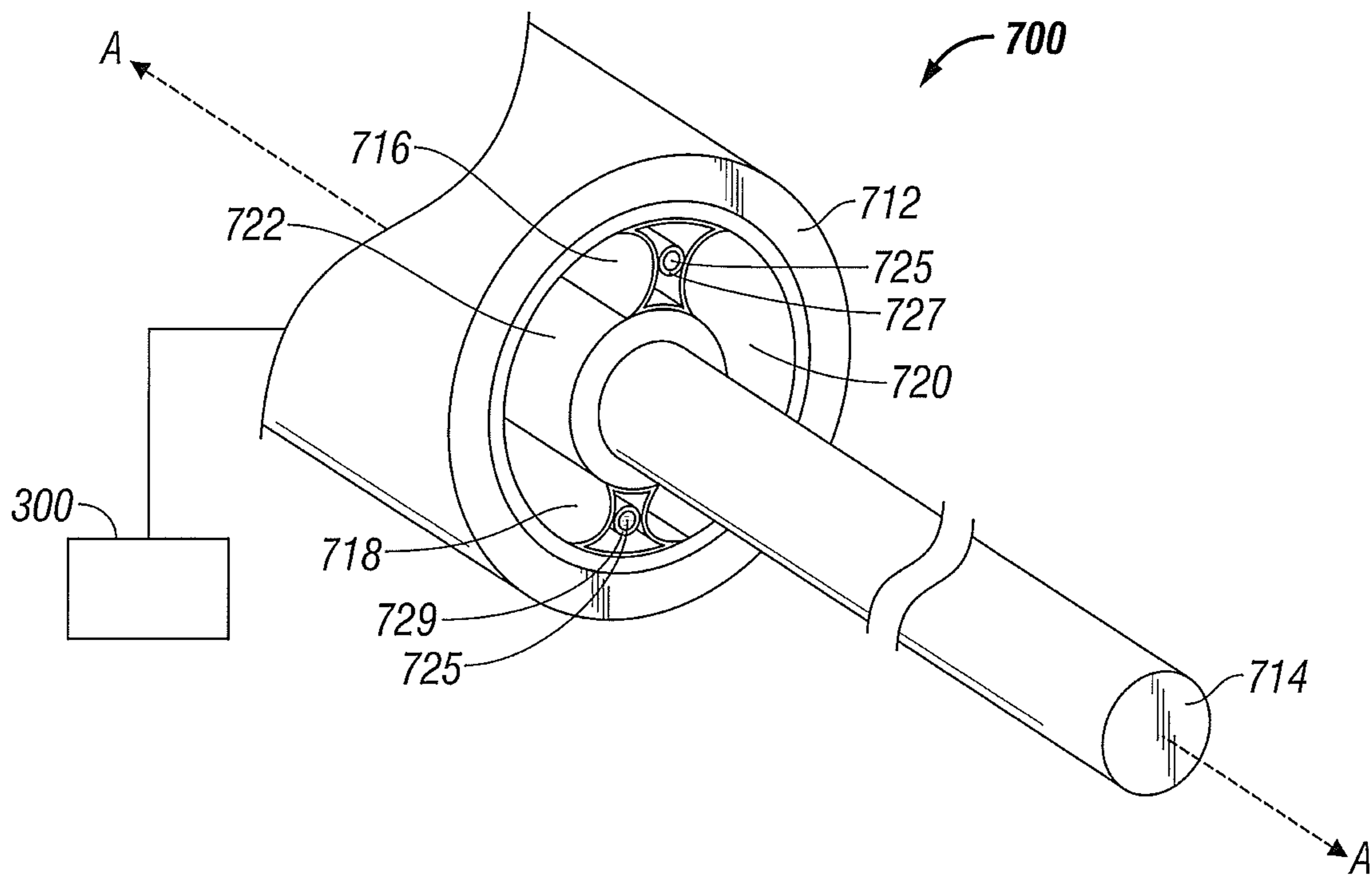


FIG. 7

## THERMALLY TUNED COAXIAL CABLE FOR MICROWAVE ANTENNAS

### CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation application of U.S. patent application Ser. No. 13/598,141, now U.S. Pat. No. 8,969,722, filed on Aug. 29, 2012, which is a continuation application of U.S. patent application Ser. No. 12/651,762, filed on Jan. 4, 2010, now U.S. Pat. No. 8,258,399, which is a continuation application of U.S. patent application Ser. No. 12/351,633, filed on Jan. 9, 2009, now U.S. Pat. No. 7,642,451, which claims the benefit of priority to U.S. Provisional Patent Application Ser. No. 61/023,029, titled "THERMALLY TUNED COAXIAL CABLE FOR MICROWAVE ANTENNAS" filed Jan. 23, 2008 by Kenlyn Bonn, all of which are incorporated by reference herein.

### BACKGROUND

#### 1. Technical Field

The present disclosure relates generally to microwave antennas. More particularly, the present disclosure relates to thermally tuning coaxial cables for microwave antennas.

#### 2. Background of Related Art

Microwave antennas are used in many applications. For example, medical microwave ablation antennas are used by surgeons. In fact, ablation devices utilizing DC shock, radio frequency (RF) current, ultrasound, microwave, direct heat, or lasers have been introduced and employed to various degrees to ablate biological tissues. Ablation devices may be used in open surgical procedures or are sometimes inserted into catheter devices in order to perform laparoscopic ablation procedures. The catheter incorporating the ablation device is generally inserted into a major vein or artery or through a body cavity. These catheters are then guided to a targeted location in the body (e.g., organ) by manipulating the catheter from the insertion point or the natural body orifice.

During ablation, the dielectric constant of the tissue changes as more water is boiled off and tissue desiccation occurs. The changing value of the dielectric constant alters the antenna's ability to match the originally designed impedance of the antenna. In addition, during microwave ablation in tissue, the impedance of the tissue varies during the course of ablation. This occurrence directly corresponds to how much energy has been deposited into the tissue during the ablation, resulting in temperature increases at the ablation site.

The impedance in the coaxial cable is typically related to the concentricity of the inner conductor in relationship to the outer conductor. In ablation procedures, however, conventional antenna designs only allow for an initial impedance match and as ablation occurs, the increase in mismatch between the tuning point of the antenna and the ablated tissue reduces the efficiency of the energy deposition in the tissue.

### SUMMARY

The present disclosure relates to a coaxial cable. The coaxial cable includes an inner conductor and an outer conductor surrounding the inner conductor configured in a generally concentric relationship therewith, the inner and outer conductors adapted to connect to an energy source. A thermally responsive material is positioned between the outer conductor and the inner conductor wherein a thermal change

in the thermally responsive material alters the generally concentric relationship between the outer conductor and the inner conductor.

The thermally responsive material of the coaxial cable may include first and second dielectric materials wherein the first dielectric material has a first coefficient of thermal expansion and the second dielectric material has a second coefficient of thermal expansion different from the first coefficient of thermal expansion.

In another embodiment, the thermally responsive material of the coaxial cable may include a first resistive heating element at least partially disposed in the first dielectric material and a second resistive heating element at least partially disposed in the second dielectric material. A thermal change may be defined by the application of heat via one or more of the first and the second resistive heating elements.

In yet another embodiment, the thermally responsive material further includes a first dielectric material that surrounds the inner conductor and a plurality of resistive heating elements disposed in the first dielectric material and substantially parallel to the inner conductor along a length of the coaxial cable. A thermal change may be defined by the application of heat to the first dielectric material via the one or more of the plurality of resistive heating elements.

In yet another embodiment, the coaxial cable includes a sensor that monitors the inner conductor and/or the outer conductor for determining a position of the inner conductor relative to the outer conductor.

In still yet another embodiment, the thermally responsive material of the coaxial cable includes a shape memory alloy responsive to changes in temperature and the thermal change in the shape memory alloy alters the generally concentric relationship between the outer conductor and the inner conductor.

In another embodiment, the thermally responsive material of the coaxial cable also includes one or more dielectric spacer(s) in a longitudinally-spaced apart relationship with respect to each other. Each of the dielectric spacer(s) includes a coefficient of thermal expansion wherein the thermal change of the thermally responsive material alters the generally concentric relationship between the outer conductor and the inner conductor at each of the plurality of spacers. The coefficient of thermal expansion of each of the plurality of spacers may not be equal.

The spacers may further include a first spacer with a first dielectric material and a first coefficient of thermal expansion and a second spacer with a second dielectric material and a second coefficient of thermal expansion. The first dielectric material and the second dielectric material may be different materials. The plurality of spacers may be in a spaced apart relationship with respect to each other.

The present disclosure also relates to a coaxial cable that includes an inner conductor and an outer conductor surrounding the inner conductor, the inner and outer conductors adapted to connect to an energy source. A first dielectric material is disposed between the inner conductor and the outer conductor, the first dielectric material having a first fluid conduit defined therein. A second dielectric material is disposed between the inner conductor and the outer conductor, the second dielectric material having a second fluid conduit defined therein. The first dielectric material and the second dielectric materials are configured to position the inner conductor in a generally concentric relationship relative to the outer conductor and are formed of thermally responsive materials wherein a change in temperature of the first or the second dielectric material alters the generally concentric relationship between the inner conductor and the outer conductor. Fluid

provided to the first fluid conduit and/or the second fluid conduit defines the change in temperature and is selectively controllable to regulate the thermal expansion of the thermally responsive material.

The present disclosure also relates to a surgical device including an inner conductor, an outer conductor surrounding the inner conductor configured in a generally concentric relationship therewith. An ablative energy delivery device is adapted to couple to an ablative energy source, through the inner and outer conductors, to deliver energy to tissue. A thermally responsive material is positioned between the outer conductor and the inner conductor wherein a thermal change in the thermally responsive material alters the generally concentric relationship between the outer conductor and the inner conductor.

The thermally responsive material selectively aligns or misaligns the inner conductor relative to the outer conductor for tuning and impedance matching. The thermally responsive material may position the inner conductor relative to the outer conductor from a first position wherein the inner conductor is concentrically-aligned with the outer conductor to a second position wherein the inner conductor is not concentrically-aligned with the outer conductor.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Various embodiments of the present disclosure are described herein with reference to the drawings wherein:

FIG. 1A is a front, perspective view of a centrally-disposed coaxial cable having an inner conductor held by two materials having different coefficient of thermal expansion values, in accordance with an embodiment of the present disclosure;

FIG. 1B is a front, perspective view of an off-center coaxial cable having an inner conductor held by two materials having different coefficient of thermal expansion values, in accordance with another embodiment of the present disclosure;

FIG. 1C is a schematically-illustrated, cross-sectional view of the coaxial cable of FIG. 1A;

FIG. 1D is a schematically-illustrated, cross-sectional view of the coaxial cable of FIG. 1B;

FIG. 2A is front, perspective view of an off-centered coaxial cable having an inner conductor held by two materials having different coefficient of thermal expansion values, in accordance with another embodiment of the present disclosure;

FIG. 2B is a front, perspective view of a centrally disposed coaxial cable having an inner conductor held by two materials having different coefficient of thermal expansion values, in accordance with another embodiment of the present disclosure;

FIG. 2C is a schematically-illustrated, cross-sectional view of the coaxial cable of FIG. 2B;

FIG. 2D is a schematically-illustrated, cross-sectional view of the coaxial cable of FIG. 2A;

FIG. 3 is a schematically illustrated, cross-sectional view of a coaxial cable having an inner conductor held by one or more spacers being composed of one or more materials having different coefficient of thermal expansion values, in accordance with another embodiment of the present disclosure;

FIG. 4A is a front, perspective view of an off-centered coaxial cable having an inner conductor and a plurality of resistive heating elements in each of two or more materials having different coefficient of thermal expansion values, in accordance with another embodiment of the present disclosure;

FIG. 4B is a front, perspective view of a centrally disposed coaxial cable having an inner conductor and a plurality of resistive heating elements in each of two or more materials having different coefficient of thermal expansion values, in accordance with another embodiment of the present disclosure;

FIG. 5A is a schematically illustrated cross-sectional view of an off-centered coaxial cable having an inner conductor and a plurality of resistive heating elements in one material having one coefficient of thermal expansion value, in accordance with another embodiment of the present disclosure;

FIG. 5B is a front, perspective view of a centrally disposed coaxial cable having an inner conductor and a plurality of resistive heating elements in one material having one coefficient of thermal expansion value, in accordance with another embodiment of the present disclosure;

FIG. 6 is a front, perspective view of a coaxial cable having an inner conductor with a shape memory alloy, in accordance with another embodiment of the present disclosure; and

FIG. 7 is a front, perspective view of a centrally-disposed coaxial cable having an inner conductor held by two materials having different coefficient of thermal expansion values with a fluid circulated therethrough for regulating the thermal expansion of the two materials in accordance with another embodiment of the present disclosure.

#### DETAILED DESCRIPTION

To achieve the foregoing and other objects of the present disclosure, methods and devices pertaining to the microwave antennas are disclosed. In general, the present disclosure pertains to a coaxial cable assembly and, in one embodiment, to a surgical device including the coaxial cable assembly. The surgical device generally includes an ablative energy source and an ablative energy delivery device coupled to the ablative energy source. The ablative energy delivery device is configured to deliver ablative energy sufficiently strong enough to cause tissue ablation. In most embodiments, the ablative energy is formed from electromagnetic energy in the microwave frequency range. Other applications are contemplated by the present disclosure, such as telecommunications or other suitable applications in which microwave antennas are utilized.

Particular embodiments of the present disclosure are described hereinbelow with reference to the accompanying drawings. In the following description, well-known functions or constructions are not described in detail to avoid obscuring the present disclosure in unnecessary detail. Those skilled in the art will understand that the present disclosure may be adapted for use with either an endoscopic instrument or an open instrument.

While the present disclosure is susceptible to embodiments in many different forms, there is shown in the drawings and will be described herein in detail one or more embodiments of the present disclosure. However, the present disclosure is to be considered an exemplification of the principles of the present disclosure, and the embodiment(s) illustrated is/are not intended to limit the spirit and scope of the present disclosure and/or the claims herein.

With reference to the drawings, the coaxial cable of the particular embodiments of the present disclosure are shown. The cable may be of any suitable length, and the figures are not intended to limit the length of the cable to a specific length illustrated or any specific length. Instead, only a representative portion or section of cable is illustrated.

Referring to the embodiment of FIGS. 1A and 1B, the coaxial cable 10 includes an outer conductor 12, an inner



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conductor **14**, a first material **16**, a second material **18**, a first air gap **20**, and a second air gap **22**. The inner conductor **14** is connected to an external power source **300**.

The coaxial cable **10** may be rigid, rigid-but shapeable or flexible. The coaxial cable **10** may be chosen from commercially available standards and is generally designed with a characteristic impedance of 50 Ohms. In addition, one side of the coaxial cable **10** may be coupled to a power supply **300**. Also, the other side of the coaxial cable **10** may be coupled to an antenna (not shown) in any suitable manner.

The outer conductor **12** is arranged to be generally concentric with respect to the inner conductor **14**. However, the concentric relationship may be configured to meet a particular purpose as explained in more detail below. Inner conductor **14** is a central conductor used for transmitting signals and is typically held relative to the outer conductor **12** by first material **16** and second material **18**. In one embodiment, the first material **16** holds the inner conductor **14**, whereas the second material **18** supports the first material **16** without contacting the inner conductor **14**. In other words, only one material contacts the inner conductor **14**.

In the illustrated embodiment, the first material **16** and the second material **18** define first and second air gaps **20**, **22** between the inner surface of the outer conductor **12** and the outer surface of the inner conductor **14**. The first air gap **20** separates a first portion of the first material **16** and a first portion of the second material **18**. The second air gap **22** separates a second portion of the first material **16** with a second portion of the second material **18**.

The inner conductor **14** has a significant effect on the coaxial cable's **10** properties, such as the cable's **10** impedance and attenuation characteristics. The impedance on the coaxial cable **10** is related to the concentricity of the inner conductor **14** in relationship to the outer conductor **12**. In the first embodiment, a thermal increase to the coaxial cable **10** is used to alter the alignment concentricity of the inner conductor **14** in a manner that would better match a change in tissue impedance. The coaxial cable **10** in the antenna (not shown) would start with an initial impedance match to a transmission line interface that would gradually taper along the length of the antenna toward a desired impedance with either the addition or the subtraction of heat. The taper could be controlled thermally through additional features, such as a cooling jacket or cooling channels.

FIGS. **1A** and **1C** illustrate the inner conductor **14** in a centered position within the coaxial cable **10**. As heat is applied, the inner conductor **14** is moved to an off-centered position due to the thermal expansion of material **18**, as shown in FIGS. **1B** and **1D**. As the tissue impedance changes, the alignment sensitivity of the cable **10** may be selectively changed (e.g., automatically or manually) such that the impedance of the cable **10** better matches the tissue impedance. One or more materials with different coefficients of thermal expansion may be utilized which mutually cooperate to tune the inner conductor **14** according to a desired setting, such as an ohmage setting.

FIGS. **2A** and **2D** show an off-centered coaxial cable **110** and FIGS. **2B** and **2C** show a centrally disposed coaxial cable **110** having an inner conductor held by two materials having different coefficient of thermal expansion values. The coaxial cable **110** includes an outer conductor **112**, an inner conductor **114**, a first material **116** and a second material **118**. The inner conductor **114** is connected to an external power source **300**.

The first material **116** has a first coefficient of thermal expansion value and the second material **118** has a second coefficient of thermal expansion value, the first and second

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coefficient of thermal expansion values being different. During heat transfer, the energy that is stored in the intermolecular bonds between atoms changes. When the stored energy increases, so does the length of the molecular bond. As a result, materials typically expand in response to heating and contract on cooling. This response to temperature change is expressed as the materials coefficient of thermal expansion. The coefficient of thermal expansion is used in two ways: (1) as a volumetric thermal expansion coefficient and (2) as a linear thermal expansion coefficient.

Therefore, when the temperature applied to the coaxial cable **110** changes, the first material **116** expands at a first rate/volume and the second material **118** expands at a second rate/volume. Typical materials used in coaxial cables include variations of PTFE, polyethylene (PE) blends and silica dioxides, however, nearly any thermo-set or thermoplastic with a low dielectric constant can be used in conjunction with another material of similar dielectric constant with a different coefficient of thermo-expansion. Typically, different polymer grades or blends result in varying material properties so determining the desired pair of materials would be a result of finding a matching mixture. The heat generated by the losses in the dielectric material in the cable can also be utilized to heat material enough to generate the differential in thermal expansion between the varying materials. A variety of different materials with different coefficient of thermal expansion values may be utilized, e.g., ABS Polymer Extruded, ABS Polymer Nylon Blend, PEEK Polyketone, PEKK Polyketone, Nylon PTFE Filled, Polycarbonate Extruded, LDPE (Polyethylene), Polyimide, PTFE Molded, Silica Aerogel and combinations thereof.

If the first material **116** expands due to a temperature increase, the second material **118** contracts due to the differing coefficient of thermal expansion values of the two materials **116**, **118**. As a result, as the ablation zone heats up, the difference in expansion between the two materials **116**, **118** would cause the inner conductor **114** to change alignment with the outer conductor **112**, e.g., move toward a centered position as illustrated in FIGS. **2B** and **2C**.

As can be appreciated, the materials **116**, **118** may be designed to selectively (e.g., either automatically or manually) align or misalign the inner conductor **114** relative to the outer conductor **112** for tuning and impedance matching purposes. In the embodiment, as seen in FIGS. **1A** and **1B**, the design could be made to start with the inner conductor **114** concentrically centered relative to outer conductor **112** and then moved off center when the temperature changes. As shown in FIGS. **2A** and **2B**, inner conductor **114** may be normally off-center relative to outer conductor **112**, and as the temperature increases, the inner conductor **114** moves toward the concentric center of the coaxial cable **110** when one of the materials **116**, **118** is heated.

The system described in regard to FIGS. **1A-2B** may include an electrosurgical generator **300** having a microprocessor and sensor circuitry (not shown) that continually monitors tissue impedance and measures offset impedance. The sensor circuitry may also continually monitor the position of the inner conductor **114** of a coaxial cable **110** with respect to a desired coaxial position (e.g., a center position). The monitor may be operably coupled to a mechanism (shape memory alloy, heat resistive element) as explained in more detail below) for regulating the thermal expansion of at least one of the first and second dielectric materials **116**, **118** to position the inner conductor **114** relative to the outer conductor **112** to change the impedance of the inner conductor **114**. The microprocessor or the circuitry may also be configured to compare the inner conductor positioning to a predetermined center

position. If the inner conductor is positioned above or below the predetermined center position, one or more materials **116**, **118** surrounding the inner conductor are heated or moved to re-position the inner conductor **114** to a desired position, and the microprocessor reports such findings to a user control or maintains this data for subsequent use.

FIG. **3** is a schematically illustrated cross-sectional view of a coaxial cable **210** having an inner conductor **214** held by one or more spacers **230**, **232**, **234** being composed of one or more materials having different coefficient of thermal expansion values. In FIG. **3**, the coaxial cable **210** includes an outer conductor **212**, an inner conductor **214**, a first material **216**, a second material **218**, a first spacer **230**, a second spacer **232** and a third spacer **234**. The inner conductor **214** is connected to an external power source **300**.

The first, second, and third spacers **230**, **232**, **234** maintain a desired position (e.g., a center position) for the inner conductor **214** for at least a partial length of the coaxial cable **210**. Each of the spacers **230**, **232**, **234** may have the same or a different width, and each may be composed of one material or two or more materials. Also, the material used for each spacer may be different. For example, a first spacer **230** may be composed of a first material **216** and a second material **218**, whereas the second and third spacers **232**, **234** may be composed of one material.

FIG. **4A** is a schematically illustrated cross-sectional view of an off-centered coaxial cable **310** and FIG. **4B** is a schematically illustrated cross-sectional view of a centrally disposed coaxial cable **310** having an inner conductor and a plurality of resistive heating elements in each of two or more materials having different coefficient of thermal expansion values. In FIGS. **4A** and **4B**, the coaxial cable **310** includes an outer conductor **312**, an inner conductor **314**, a first material **316**, a second material **318**, first resistive heating elements **340** and second resistive heating elements **342**.

FIG. **4A** illustrates the inner conductor **314** in an off-centered position within the coaxial cable **310**. As heat is applied via the heating resistive elements **340**, **342** shown in FIG. **4B**, the inner conductor **314** moves to a centered position due to the thermal expansion of material **318**. As the tissue impedance changes, the alignment sensitivity of the cable **310** may be selectively changed (e.g., automatically or manually) such that the impedance of the cable **310** better matches the tissue impedance. One or more materials may be utilized to tune the inner conductor **314** according to a desired setting, such as an ohmage setting.

A plurality of first resistive heating elements **340** may be positioned in first material **316** and a plurality of second resistive heating elements **342** may be positioned in second material **318**. The first and second resistive heating elements **340**, **342** convert electricity into heat. Electrical current running through the elements encounter resistance, thus resulting in heating of the element. Resistive heating elements **340**, **342** may be made from Nichrome which has a relatively high resistance and does not break down or oxidize in air at useful temperature ranges. First and second resistive heating elements **340**, **342** may also be positioned in parallel to the inner conductor **314**, at various lengths from the inner conductor **314**, and in various widths. The temperature of each of the plurality of heating elements **340**, **342** may be selectively controllable to position the inner conductor **314** relative to the outer conductor **312** and the plurality of heating elements **340**, **342** may be disposed in a concentric array relative to the inner conductor **314**.

FIG. **5A** is a schematically illustrated cross-sectional view of an off-centered coaxial cable **410** and FIG. **5B** is a schematically illustrated cross-sectional view of a centrally dis-

posed coaxial cable **410**. In FIGS. **5A** and **5B**, the coaxial cable **410** includes an outer conductor **412**, an inner conductor **414**, a dielectric material **416**, and one or more resistive heating elements **440**. In contrast to FIGS. **4A** and **4B**, only one dielectric material **416** is used to surround the entire length of the inner conductor **414**. The dielectric material **416** includes one or more resistive heating elements **440** in parallel to the inner conductor **414** along the length of the cable **410**. More particularly, the resistive heating elements **440** are positioned in parallel to the inner conductor **414**, at various lengths along the inner conductor **414**, and in various widths.

FIG. **5A** illustrates the inner conductor **414** in an off-centered position within the dielectric material **416**. As heat is applied, the inner conductor **414** is moved to a desired position (e.g., a center position) due to the thermal expansion of dielectric material **416** and due to first resistive heating element **440b** being heated to expand the dielectric material **416** in a given direction. Any member or combination of heating elements **440a-440e** may be utilized to move the inner conductor **414** for tuning purposes. As the tissue impedance changes, the alignment sensitivity of the cable **410** may be selectively changed (e.g., automatically or manually) such that the impedance of the cable **410** better matches the tissue impedance.

FIG. **6** is a schematically illustrated cross-sectional view of a coaxial cable having an inner conductor with a shape memory alloy **550** in accordance with another embodiment of the present disclosure. In FIG. **6**, the coaxial cable **510** includes an outer conductor **512**, an inner conductor **514**, a dielectric material **516** and a shape memory alloy **550**.

The shape memory alloy **550** is, for example, positioned in proximity to the inner conductor **514**. One or more shape memory alloys **550** may be positioned along the length of the coaxial cable **510** in predetermined distance from each other.

Shape memory alloys (SMAs) are a family of alloys having anthropomorphic qualities of memory and trainability and are particularly well suited for use with medical instruments. SMAs have been applied to such items as actuators for control systems, steerable catheters and clamps. One of the most common SMAs is Nitinol which can retain shape memories for two different physical configurations and changes shape as a function of temperature. Recently, other SMAs have been developed based on copper, zinc and aluminum and have similar shape memory retaining features.

SMAs undergo a crystalline phase transition upon applied temperature and/or stress variations. A particularly useful attribute of SMAs is that after it is deformed by temperature/stress, it can completely recover its original shape on being returned to the original temperature. The ability of an alloy to possess shape memory is a result of the fact that the alloy undergoes a reversible transformation from an austenitic state to a martensitic state with a change in temperature/stress. This transformation is referred to as a thermoelastic martensitic transformation.

Under normal conditions, the thermoelastic martensitic transformation occurs over a temperature range which varies with the composition of the alloy, itself, and the type of thermal-mechanical processing by which it was manufactured. In other words, the temperature at which a shape is "memorized" by an SMA is a function of the temperature at which the martensite and austenite crystals form in that particular alloy. For example, Nitinol alloys can be fabricated so that the shape memory effect will occur over a wide range of temperatures, e.g., -2700 to +1000 Celsius. Many SMAs are also known to display stress-induced martensite (SIM)

which occurs when the alloy is deformed from its original austenitic state to a martensitic state by subjecting the alloy to a stress condition.

As a result, when heat is applied to the coaxial cable **510**, the inner conductor **514** tends to move from its desired position within the coaxial cable **510**. SMA **550**, which is embedded within a material **516** having a certain coefficient of thermal expansion and which is located in a close proximity to the inner conductor **514** may move the inner conductor **514** back to its desired position (e.g., a center position) within the coaxial cable **510**. SMA **550** can recover from large amounts of bending and torsional deformations, due to the application of heat, as well as small amounts of strain. Provided the deformations are within recoverable ranges, the process of deformation and shape recovery can be repeated millions of times. As a result, the SMA **550** located within the material **516** can repeatedly move the inner conductor **514** back to a desired position (e.g., a centered position). Moreover, as can be appreciated, the material **516** may be designed to selectively (e.g., either automatically or manually) align or misalign the inner conductor **514** relative to the outer conductor **512** for tuning and impedance matching purposes.

Consequently, the embodiments of the present disclosure allow for improved antenna impedance matching for controlling tissue impedance of a microwave antenna during an ablation procedure via a thermally tuned coaxial cable. The embodiments further include changing the impedance of the coaxial cable for allowing greater flexibility in designing microwave antennas. By having a varying impedance of the coaxial cable in the antenna tuned to change with the increase/decrease in temperature, tissue impedance changes, and thus, the antenna may deposit a greater amount of energy over the entire course of the ablation procedure. By using dielectric cores of varying thermal expansion values, it is possible to force the eccentricity of the inner conductor of the coaxial cable on-line or off-line, thus effectively changing the coaxial cable's impedance value.

In addition, FIGS. 1A-2D illustrate two materials **16**, **18** within the spacing between the inner surface of the outer conductor **12** and the outer surface of the inner conductor **14** including two air spaces or gaps **20**, **22**. However, one skilled in the art may use more than two materials within the spacing between the inner surface of the outer conductor **12** and the outer surface of the inner conductor **14** and more than two air gaps. For example, one skilled in the art may be motivated to use three or more materials, each with a different coefficient of thermal expansion value in a triangular configuration with three or more air gaps separating the materials. In addition, one skilled in the art may be motivated to use two materials in a checkered pattern or any other type of intertwined pattern with one or more air gaps in order to center or off-center the inner conductor **14** of the coaxial cable **10** as needed to tune or match the tissue impedance.

Further, in FIGS. 1A-6 there may be one or more mechanisms that regulate the thermal expansion of at least one of the first and second dielectric materials **16**, **18** to position the inner conductor **14** relative to the outer conductor **12** to change the impedance of the inner conductor **14**.

FIG. 7 shows another embodiment according to the present disclosure wherein the coaxial cable **700** includes an outer conductor **712** arranged to be generally concentric with respect to the inner conductor **714** used for transmitting signals. Inner conductor **714** is held relative to the outer conductor **712** by first material **716** and second material **718** only one of which contacts inner conductor **714**. First material **716** and the second material **718** define first and second air gaps **720** and **722**, respectively, between the inner surface of the outer

conductor **712** and the outer surface of the inner conductor **714**. A fluid **725** is circulated within one or both the first and second dielectric materials **716**, **718** via conduits **727** and **729** defined respectively therein. The relative temperature of the fluid **725** may be selectively controllable via circuitry controlled by the generator **300** to regulate thermal expansion of one or both the first and second dielectric materials **716**, **718** to position the inner conductor **714** relative to the outer conductor **712** to change the impedance of the inner conductor **714**. The fluid **725** may optionally or alternatively be disposed between the first and second dielectric materials **716**, **718** and be controlled in a similar manner.

While several embodiments of the disclosure have been shown in the drawings and/or discussed herein, it is not intended that the disclosure be limited thereto, as it is intended that the disclosure be as broad in scope as the art will allow and that the specification be read likewise. Therefore, the above description should not be construed as limiting, but merely as examples of particular embodiments. Those skilled in the art will envision other modifications within the scope and spirit of the claims appended hereto.

What is claimed is:

1. A method for controlling alignment of an inner conductor and an outer conductor of a coaxial cable of a microwave antenna, the method comprising:

changing a temperature of at least one thermally responsive material disposed between an inner conductor and an outer conductor of a coaxial cable of a microwave antenna, the inner conductor being disposed within the outer conductor,

wherein a change in temperature of the at least one thermally responsive material alters alignment of the inner conductor within the outer conductor.

2. The method according to claim 1, wherein the at least one thermally responsive material is a dielectric.

3. The method according to claim 1, wherein changing the temperature of the at least one thermally responsive material includes heating the thermally responsive material via a plurality of resistive heating elements disposed within the thermally responsive material.

4. The method according to claim 1, wherein the at least one thermally responsive material includes a shape memory alloy.

5. The method according to claim 1, wherein the at least one thermally responsive material includes a plurality of spacers disposed in a longitudinally spaced apart relationship with respect to each other.

6. The method according to claim 1, further comprising: tuning the microwave antenna by altering the alignment of the inner conductor within the outer conductor.

7. The method according to claim 1, wherein tuning further includes repositioning the inner conductor within the outer conductor from a first position wherein the inner conductor is concentrically aligned with the outer conductor to a second position wherein the inner conductor is not concentrically aligned with the outer conductor.

8. The method according to claim 1, further comprising: monitoring the position of the inner conductor relative to the outer conductor.

9. A method for controlling impedance of a coaxial cable of a microwave probe, the method comprising:

measuring impedance of a coaxial cable, the coaxial cable coupling a microwave probe to a microwave generator; determining whether the impedance of the coaxial cable substantially matches impedance of at least one of the microwave generator or the microwave probe; and

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changing a temperature of at least one thermally responsive material disposed between an inner conductor and an outer conductor of a coaxial cable of a microwave antenna based on the determination, the inner conductor being disposed within the outer conductor,

wherein a change in temperature of the at least one thermally responsive material alters alignment of the inner conductor within the outer conductor to substantially match the impedance of the at least one of the microwave generator or the microwave probe to the coaxial cable.

**10.** The method according to claim **9**, wherein the at least one thermally responsive material is a dielectric.

**11.** The method according to claim **9**, wherein changing the temperature of the at least one thermally responsive material includes heating the thermally responsive material via a plurality of resistive heating elements disposed within the thermally responsive material.

**12.** The method according to claim **9**, wherein the at least one thermally responsive material includes a shape memory alloy.

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**13.** The method according to claim **9**, wherein the thermally responsive material includes a plurality of spacers disposed in a longitudinally spaced apart relationship with respect to each other.

**14.** The method according to claim **9**, further comprising: tuning the microwave antenna by altering the alignment of the inner conductor within the outer conductor.

**15.** The method according to claim **14**, wherein tuning further includes positioning the inner conductor relative to the outer conductor from a first position wherein the inner conductor is concentrically aligned with the outer conductor to a second position wherein the inner conductor is not concentrically aligned within the outer conductor.

**16.** The method according to claim **9**, further comprising: monitoring the position of the inner conductor within the outer conductor.

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